Effects of rainfall variability on farm income disparity and inequity in a small catchment of Northern-Thailand : a multi-agent simulation investigation

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Résumé
Cet article présente une approche de modélisation se basant sur les systèmes multi-agents pour évaluer les effets de la variabilité interannuelle de la pluviométrie sur les disparités économiques entre des exploitations agricoles se partageant la ressource en eau. Le cas d'étude est un bassin versant du Nord-Thaïlande où deux villages se partagent l'eau pour l'irrigation agricole. Les données d'entrées ont été collectées et le modèle a été calibré pour ce terrain d'étude et les résultats présentés sont issus des simulations réalisées. Ces dernières montrent que les événements de sécheresse tendent à accroître les inégalités entre les exploitations agricoles, tant en terme de marge brute que de revenu agricole, et ce aussi bien à l'échelle intra-villageoise, qu'entre les deux villages se partageant la ressource en eau. Des analyses complémentaires indiquent qu'un accroissement des inégalités s'opère également lorsque des changements d'occupation du sol, engendrant une augmentation des besoins en eau, surviennent. L'iniquité économique entre les usagers d'une même ressource serait donc corrélée positivement au niveau de pression exercé sur cette ressource et s'explique en grande partie par l'hétérogénéité d'accès à la ressource. C'est pourquoi, dans le contexte du changement climatique, cet article plaide pour un usage plus systématique d'outils dévaluation économique capables de prendre en compte les hétérogénéités d'accès spatiales et temporelles à la ressource, tels que la simulation multi-agents, afin de révéler et d'anticiper les effets sur les inégalités.

Mots-clés : agriculture, disparité économique, Nord-Thaïlande, simulation multi-agent, variabilité pluviométrique

Abstract
This paper presents a modeling approach, based on multi-agent-systems, for assessing the effects of inter-annual rainfall variability on income disparity among farms sharing water resource. The study case is a catchment of northern-Thailand where two villages share water for irrigation. Input data were collected and the model was calibrated for this study case and the results described here originate from the simulations undertook. They show that stress events such as dry years tend to increase economic disparities among farms (gross margins and farm income), both at the village scale and between the two villages sharing water. Additional analyses indicate that land-use change which increase irrigation demand, tend to increase farm inequity as well. As so, in contexts of limited resources and due to heterogeneity of resource access and means, inequity among user groups would be positively correlated to the pressure on the resource. Consequently and in the context of climate change, this paper advocates for a wider use of economic assessment tools capable of taking into account spatial and temporal heterogeneity of resource access, such as multi-agent simulations, in order to monitor and anticipate effects on inequity.

Keywords: agriculture, income disparity, multi-agent simulation, northern-Thailand, rainfall variability

INTRODUCTION

The World development report 2008 (World Bank, 2008) entitled "Agriculture for development" stresses that in transforming countries, which include most of South and East Asia and the Middle East and North Africa, the main target should be to narrow the rapidly rising rural-urban income disparities and reduce extreme rural poverty. Competition over natural resources (water, land, ...) and great economic and social heterogeneity defining those rural areas require policies to be differentiated according to the status and context of households. At the same time, the World development report 2010 (World Bank, 2010) entitled "Development and climate change" points that climate change is likely to affect the amplitude and frequency of world's monsoons and El Niño/Southern Oscillation. In a region such as Northern-Thailand, we expect, among other consequences, variability in the timing of monsoon and increasing inter-annual rainfall variability. This inflection in development strategy magnified by the expected effects of climate change on water availability for agriculture requires having tools and methods to monitor economic disparities and assess how they may be impacted by changes and modified through policies or innovations.

Traditionally, economic analysis of farming systems in a given area often results in an estimation of various indicators (e.g. gross margins, farm income) calculated as an average for the farm population or a sample, or for typical/representative farms (see for example USDA, 2010, APCA, 2010). It is well known that those average values of indicators may hide huge disparities among individual farms, throwing back into doubt the reliability of the analysis. Standard deviation or statistical tests help assessing the reliability of the results, but then again the focus is on the sample's homogeneity and not on intrinsic disparities.

One aspect that could explain why we commonly focus on such an overall approach is that economics have long been studied and modeled using a single representative agent, which serves as reference for economic calculation. Another approach is in establishing 'typical farms' which are not corresponding to any existing farm but give an idea of the different farm clusters found in the area[1]. Yet, today's computing power offers alternative approaches. When data are available for individual farms, calculating and simulating the evolution of economic indicators for each single farm of a population becomes an option. We thus move on from an aggregated overall analysis to a distributed heterogeneity-based assessment.

Multi-agent simulations offer such a possibility. This paper proposes an approach enhancing farming systems economic analysis by taking into account the multiplicity of situations, by investigating disparities between farms and by assessing inequity within the farm population. Using various scenarios, the simulation tool estimates the effects of inter-annual rainfall variability and of alternative land uses on these economic indicators. Other multi-agent models exist for simulating the effects of rainfall variability on agriculture, like in Lacombe *et al.* (2005) or Bithell and Brasington (2009). The innovative aspect of this paper is to characterize its impacts on farming system economic results and disparities.

I first present the case study and the background of this research. The multi-agent simulation model used and the Farming System Economic Monitoring (FSEM) module developed are then described. Simulation outputs are then analyzed and discussed. Finally, I draw conclusions on inequity and response to changes and on the benefits of using multi-agent simulation to study agricultural inequity.

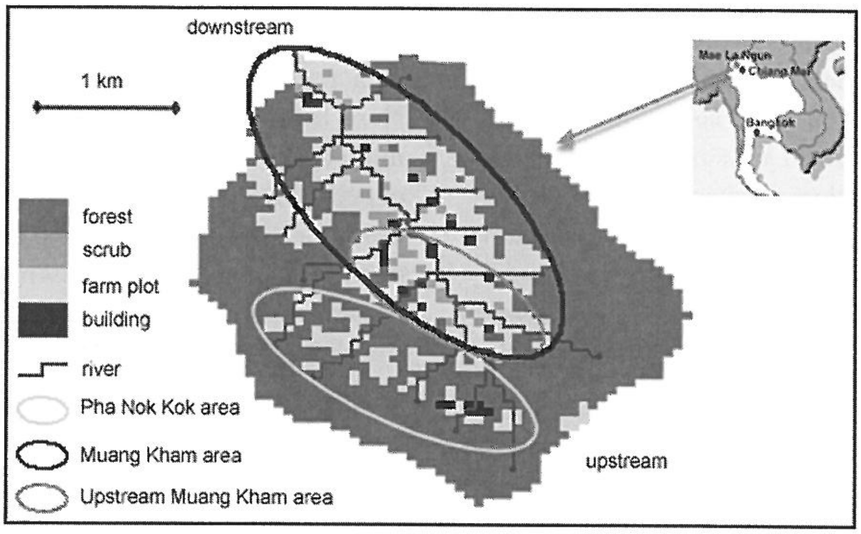
1. A CASE STUDY INVOLVING TWO COMMUNITIES CONFLICTING FOR WATER

The area under study is a small catchment of 6,88 km^2 in Chiang Mai province - Northern Thailand. It involves two villages located upstream/downstream from each other along the Mae La Ngun river (see Figure 1). Muang Kham is a lowland Northern Thai village (167 farms within Mae La Ngun catchment) growing irrigated high-value cash crops all year long: sweet pepper using dripping irrigation, chrysanthemum and vegetables. Pha Nok Kok is an upland Hmong village (21 farms within Mae La Ngun catchment) cultivating lychee (partially irrigated during the dry season), gerbera cut-flowers (biannual crop, harvested and irrigated all year) and vegetables mainly cultivated during rainy season.

The issue under study is on the upstream-downstream water allocation between these two villages. The conflict starts back in 1999 when water was very scarce during dry season and villagers from Muang Kham complained that Pha Nok Kok farmers were using too much water (Neef *et al.*, 2003). As causes for drought, farmers mentioned the increasing use of water and water users in the uplands. After negotiation, villagers found a provisional arrangement, but still, occasionally, at the end of dry season, water shortages occur. Parallel to this, dripping irrigation was developed

[1] This approach is for instance used by most regional farm bureau in France (Chambre d'Agriculture) such as for instance in Picardie (APCA, 2010)

Figure 1: Land cover map and villages' agricultural area of Mae La Ngun catchment



in Muang Kham for sweet pepper production and some farmers invested in private groundwater wells to secure water availability. However, village headmen and/or representatives were still looking for a permanent and satisfying solution to this water allocation problem five years later. The situation of Mae La Ngun catchment is a typical example of water conflicts occurring in Northern Thailand, with an ethnic minority located in the mountains and a Thai community in the plain.

In 2004, the Uplands Program[2] (SFB 564) initiated a participatory research project in this catchment consisting in the use of simulation models with local stakeholders in order to provide guidance for defining new management rules and consider alternative solutions (see Uplands Program 2006 for more details on this research program). The project was conducted using companion modeling approach which involves model co-development together with the stakeholders, defining model's rules, assumptions, scenarios, ...; and uses models as a medium of communication between groups having contrasting viewpoints and objectives (ComMod, 2003). Results of this participatory research are given in Becu *et al.* (2008). One of the outcomes of this research was the definition by the stakeholders of prospective scenarios trying to resolve the upstream-downstream water allocation issue. The simulation results for these different scenarios were analyzed in terms of reduction of water scarcity of the different communities. Yet, this study lack to analyze the economic impacts for farms and water user groups.

In this paper, I developed an economic monitoring module plugged to the model previously defined and used it to conduct a simulation analysis focusing on farms' economic disparities for the different scenarios that had been identified by the stakeholders. In order to calibrate the economic module I benefited from the large database of the Uplands Program, including (i) a farm survey done in 2002 on 6 farms in Pha Nok Kok village and 8 farms in Muang Kham village (Uplands Program, D3 project) and (ii) a farm/household survey done in 2003 on 12 farms in Pha Nok Kok village and 30 farms in Muang Kham village (Uplands Program F1.2/NRCT project).

The two components of this modeling exercise, the MAS model and the economic module, are now described.

2. A MULTI-AGENT MODEL SIMULATING CROP YIELDS DEPENDING ON AGRICULTURAL PRACTICES, WEATHER CONDITION AND HYDROLOGICAL DYNAMICS

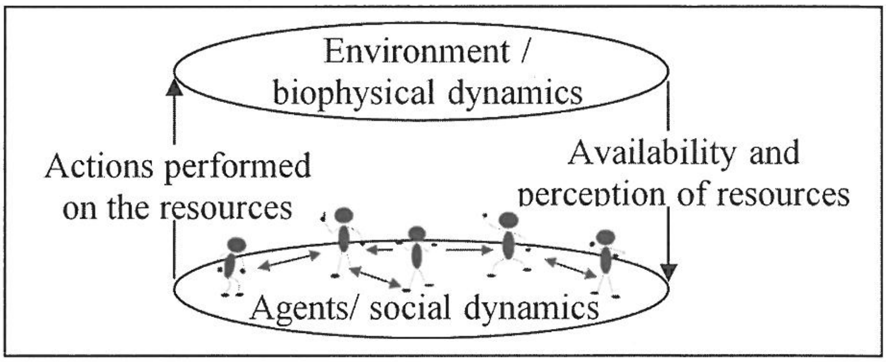
Multi-agent models are representations of reality that consist in modeling interactions between elementary entities in order to simulate the emergence of global phenomenon at a higher level of observation (Ferber, 1999). It usually consists of two layers: one to model the biophysical dynamics and a second one modeling the

[2] See https://sfb564.uni-hohenheim.de and the 2006 symposium

social dynamics. As the biophysical components evolve, the activities and management decisions carried out by the agents evolve and vice versa. 'Agent' refers to a decision making entity of the social system. In our case, agents are farmers undertaking production activities and managing resources. The biophysical dynamics refer to all the natural processes involved in the evolution of resources (mainly water). Hence, the model simulates in a discrete mode, the co-evolution of farmers activities and hydrological dynamics.

The multi-agent model used is based on CatchScape3 (Becu, Perez *et al.*, 2003) and was adapted to Mae La Ngun catchment and described in a previous paper (Becu, Neef *et al.*, 2008). Here below I present a summary of the main model characteristics based on the previous papers (§2.1). Then I describe the input data used for this paper as well as the validation phase (§2.2). Finally, I present unpublished simulation results (simulated yield in particular) stemming from new model developments (§2.3).

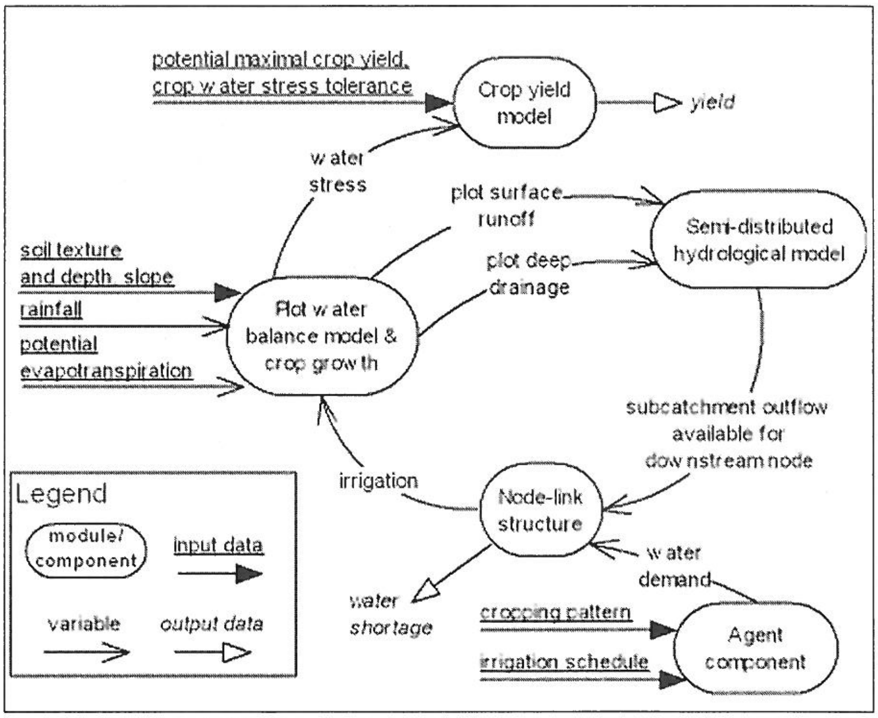
Figure 2: Modeling the co-evolution between stakeholders and their environment



2.1. Model components and scheduling

The model uses discrete time steps, each corresponding to a period of 10 days. Plots are spatially represented in a spatial grid of 66x53 cells. Each plot corresponds to an area of 2 rai (a Thai unit of area equal to 0.16 hectare). The set of plots represents the area of the catchment. A digital elevation model of the catchment is used to delineate sub-catchments that are used to estimate water discharge.

Figure 3: CatchScape3 modules and data flows



Source: Becu *et al.*, 2008.

The biophysical component consists of four different modules which have been calibrated earlier for neighboring catchments.

- Water balance module calculates water transfer at the plot level (runoff and infiltration, then actual evapotranspiration, then deep drainage) depending on weather condition, soil types, crops' water consumption and irrigation volume.
- Semi-distributed hydrological module aggregates plots' surface runoff and plots' deep drainage at the sub-catchment level and then calculates water discharge at the outlet of the sub-catchment, called a node.
- Node-link module represents the hydrological network of the studied catchment. It orders sub-catchments in an upstream/downstream order. For each sub-catchment, it calculates how much of the water demand can be satisfied depending on the water discharge at the corresponding node.
- Crop yield module estimates yields according to (1) potential crop yields and water stress tolerance in the study area, (2) and aggregated total water stress during the cropping period simulated by the water balance module.

The agent component[3] models farmers' decisions about crops to cultivate and irrigation volume to be allocated for each cultivated plot on a period of 10 days. This volume is the water demand. Each farmer may have several plots on which he can grow different crops. The actions performed by the farmers are planting, irrigating, and harvesting crops. Once harvested, the data on yield and crop harvested are processed by the Farming System Economic Monitoring module as explained later.

The scheduling of each time step is as follows. First, the agents' component calculates the water demand for each plot. Second, rainfall and potential evapotranspiration for the given period are assigned to each plot. Third, the biophysical component calculates plots' water transfer and distributes irrigation to plots according to water demand and water availability for each sub-catchment, starting from the most upstream one until the most downstream one. Depending on water availability in the sub-catchment, the water demand may be satisfied or not. Fourth, a new state of the environment is calculated (i.e., plots' water content, crop water stress, percentage of water demand met). When the cropping period of a plot ends, the farmer owing that plot performs its harvesting action and the crop yield is calculated. This new state serves as reference for farmers to take decisions at the next time step.

2.2. Input data and validation for Mae La Ngun catchment

Soil types, depth, slopes, land cover and other land characteristics were imported from GIS maps produced by the Uplands Program (data originates in particular from the Thai Land Development Department). Rainfall and potential evapotranspiration are the only input variable of the biophysical component (others are parameters or input data not varying over time). Climatic datasets originates from the weather station of Mae Sa Mai located 4 kilometers east from the catchment. Out from a dataset covering 12 years of climatic records, three different hydrologic years (an hydrologic year in Northern Thailand starts approximately in May and ends in April) were extracted corresponding each to a typical annual weather condition. The first is the hydrologic year 2004-2005 which corresponds to a rainy year (≈1 700 mm). The second one is the climatic year 2002-2003 and it corresponds to a year with average rainfall (≈1 400 mm). Finally, the year 2003-2004 corresponds to a dry year (≈1 000 mm). In the following of this paper, I will refer to these three weather condition as rainy year, standard year and dry year.

Farmers in the model make decisions about crops to cultivate. To model this choice, we used data from several agricultural surveys, as well as suggestions and comments from Mae La Ngun farmers which were collected during the model co-development process undertaken in the earlier participatory research project. Different farming systems were identified: two for the upland village Pha Nok Kok, and three for the lowland village Muang Kham (Table 1). In addition, three

[3] Three classes of agents, each corresponding to a water use in the catchment, are modeled: upstream and downstream farms using water to irrigate crops, drinking water company, and village household water consumption. Even though simulations are made with all three types of agents, the results presented in this paper concern farms. We therefore describe here below the behavior of the Farmer class and refer to Becu *et al.* (2008) for a presentation of the other agent types of the model.

scenarios with different land use were identified by the farmers and integrated in the model. The baseline scenario corresponds to what was cropped in year 2005. The SweetPepper scenario assumes more sweet pepper cultivated in Muang Kham than the baseline and the Gerbera scenario considers more gerbera in Pha Nok Kok than the baseline. To model these three scenarios, the number of farmers belonging to each farming system type was adjusted. For instance, for the baseline scenario, the simulation is done with 21 farmers of farming system type 1 for Pha Nok Kok village and with 60, 32 and 75 farmers of farming system type 1, 2 and 3 respectively for Muang Kham village (Table 1).

All farms own three plots. For Pha Nok Kok, they cultivate one plot of lychee and one plot of gerbera all year long. For the baseline and SweetPepper scenario, the third plot is used for vegetables; each time a farmer plants his vegetable plot, he picks randomly from one of chayote, Chinese cabbage or cabbage. The vegetable plot is not cultivated during warm season (Feb.-April)[4]. For Gerbera scenario most farmers (18 out of 21), cultivate gerbera on the third plot. The irrigation schedule for all these crops consists in a water demand of 5 liters per m^2 every day during the whole dry season except for lychee which is not irrigated in February (flowering). Water demand may or not be satisfied, depending on the result of the biophysical model component. For the lowland village Muang Kham, there are three types of farming system: the one that grows only vegetables (chayote, Chinese cabbage or green bean), the one growing vegetables and chrysanthemum and a third type cultivating sweet pepper in addition to the two others. For SweetPepper scenario, the number of farming system type 3 cultivating sweet pepper is increased by 50%, as compared to the baseline and to the Gerbera scenario (table1). The irrigation schedule is similar to the one of farmers from Pha Nok Kok, except for sweet pepper which uses drip irrigation and consumes 10 times less water.

Table 1: Farming systems implemented in baseline and prospective scenarios

	Pha Nok Kok		Muang Kham		
	Type 1	Type 2	Type 1	Type 2	Type 3
Plot n°1 Plot n°2 Plot n°3	Lychee Gerbera Vegetables	Lychee Gerbera Gerbera	Vegetables Vegetables Vegetables	Chrysanthemum Vegetables Vegetables	Sweet pepper Chrysanthemum Vegetables
Crop rotation	Lychee and gerbera are cultivated all year long. Vegetables are not cultivated in warm season.		All plots are continuously cultivated (almost no fallow period)		
Irrigation	All crops: 5 liters /m^2 /day (lychee are not irrigated in February - flowering)		Chrysanthemum, vegetables: 5 liter /m^2 /day. Sweet pepper: 0,5 liter /m^2 /day		
Baseline scenario	21 farmers	-	60 farmers	32 farmers	75 farmers
SweetPepper sc.	21 farmers	-	56 farmers	-	111 farmers
Gerbera scenario	3 farmers	18 farmers	60 farmers	32 farmers	75 farmers

It is important to note that in this application to Mae La Ngun catchment, the irrigation schedule is the only element that determines the water demand for each cultivated plot. This amount is not necessarily what the plot will actually receive; it depends on the water supply available in each sub-catchment simulated by the biophysical component. Yet, apart from seasonal changes in land use, the agricultural water demand is constant in the model. This simplistic representation of water demand is the result of the participatory model co-development process and was certainly beneficial in that view as it made the model much easier to discuss and assess in a participatory context. Yet, we must pay attention that in this application, there is no feedback between the

[4] The implementation of this rule in the model was asked by the farmers. It corresponds to a negotiation that took place in 1999 between the two villages.

water balance and farmer's decisions regarding crop choice and irrigation schedule. In reality, farmers adjust the types of crop cultivated or adopt different irrigation methods as a response to changes in water supply. Such an adaptation has been modeled for instance in Berger (2001) or Becu *et al.* (2003), but in the present application it was not the option chosen.

The model was validated by comparing the catchment outlet simulated discharge (using baseline scenario) with gauged outlet discharge of a neighboring catchment of an equivalent area[5] on the period 2001-2004 (Figure 4 shows the comparison of simulated and observed discharge from rainy season 2002 to dry season 2003, standard year). CatchScape3 hydrological module tends to overestimate outlet discharge during peak flows and underestimate it during dry season low-water. However the error margin during dry season - which is the critical period for the purpose of this modeling exercise - remains below 15% which was considered as acceptable. As MAS models are often stochastic (mostly concerning agents' decisions), the variability of the results has to be verified. On 30 repetitions of the same scenario, the standard deviation of the simulated outlet discharge was less than 0.001 m^3/sec and the variation of the number of plots lacking water from one repetition to another was less than 2.2% which was considered as an acceptable range.

2.3. Simulation outputs in terms of water shortage and yield

The output indicators presented here are of three kinds. First, the number of days during which irrigated crops faced a severe water shortage during dry season (~November-March/April). Second, the average percentage of water demand that was not satisfied by the biophysical component due to insufficient water supply, during dry season. Third, the average percentage of yield reductions calculated as the ratio between the simulated actual yields and the yield potential in water unconstrained condition. All these indicators are average values for a set of plots. They are calculated for three areas of the catchment (Figure 1): first the cultivated area of Pha Nok Kok (83 plots); second, the upstream part of Muang Kham corresponding to farms using water from the same streams as Pha Nok Kok farmers (71 plots); third, the downstream part of Muang Kham corresponding to all the other farms of Muang Kham (430 plots). The distinction between the up stream and downstream parts of Muang Kham agricultural areas was made in order to better assess the effects of Pha Nok Kok farming practices on Muang Kham farms.

Table 2: Simulated water shortage and yields for baseline scenario

	Rainy year			Standard year			Dry year		
	Shortage Period (days)	Unsatisfied water demand (%)	Yield reduction (%)	Shortage Period (days)	Unsatisfied water demand (%)	Yield reduction (%)	Shortage Period (days)	Unsatisfied water demand (%)	Yield reduction (%)
MK downstream	0	-	11	10	46	15	10	69	18
MK upstream	40	20	15	70	26	31	130	58	56
Pha Nok Kok	60	26	19	80	24	32	130	60	59

Source : Becu *et al.*, 2008.

Table 2 presents the results of the three weather condition for the baseline scenario. It shows that water stress increases when going from downstream to upstream. This is due to lower river discharge and to high water demand in the upstream. In all three weather condition, simulation outputs indicate that the lack of water for Pha Nok Kok and for the upstream part of Muang Kham are in the same range, while the downstream part of Muang Kham is rarely short of water. Yet, the drier the year, the greater the lack of water. The loss in crop yields is most severe in dry years and the upstream part of Muang Kham is again in the same range than Pha Nok Kok. Still, the later suffers slightly greater yield depletion than their downstream peers, due to gerbera cut-flower cultivation which is highly sensitive to water stress. This may have significant economic consequences, as gerbera is the main source of income of Pha Nok Kok farms.

[5] Mae La Ngun is an ungauged catchment. We therefore used secondary data to calibrate and validate the hydrological module.

This aspect will be analyzed in the next section. Table 3 presents the number of days severely short of water, during a standard hydrologic year, for the three different scenarios defined as well as for a fourth scenario defined by stakeholders in which a water reservoir is implemented in Pha Nok Kok region and used by the farmers of this area[6].

Table 3: Simulation results of three scenarios in terms of duration of shortage period (days)

	Baseline sc.	SweetPepper sc.	Gerbera sc.	Baseline sc. with reservoir
Muang Kham upstream	70	0	90	60
Pha Nok Kok	80	80	90	30

Simulation results show that SweetPepper scenario solves the problem of water shortage in Muang Kham thanks to drip irrigation system used for sweet pepper cultivation. Gerbera scenario increases water shortage in both villages. The fact that gerbera is cultivated all year round, while vegetables are not grown during the dry season, explains this result. The use of a reservoir in Pha Nok Kok would substantially reduce water scarcity in Pha Nok Kok and would benefit as well to Muang Kham upstream area. This secondary effect is the consequence of a reduced water withdrawal from the stream by Pha Nok Kok farmers during the dry season, letting more water to flow downstream.

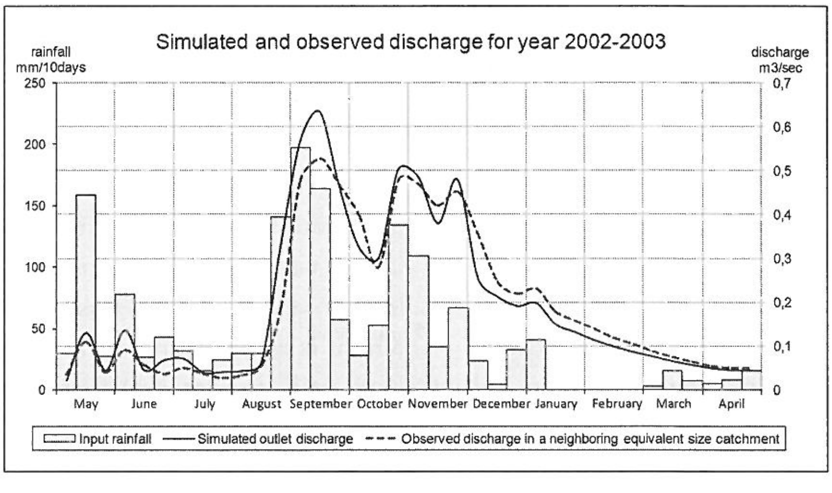
The question remains: what would be the welfare effects of those scenarios? How much can the welfare of both villages be increased when reducing the water shortages and what are the costs? Even though water shortages increase with a shift to gerbera production, the total welfare effect could well be positive if gerbera is very profitable. Is the additional profit enough to cover the initial investment costs for building a reservoir or buying equipment for sweet pepper cultivation (green houses and drip irrigation)? The farming systems economic analysis presented in the next section answers some of these questions.

3. ECONOMIC ASSESSMENT OF THE IMPACT OF WEATHER CONDITION AND ALTERNATIVE PRODUCTION SYSTEMS

3.1. Farming System Economic Monitoring module

A Farming System Economic Monitoring module (FSEM) was developed for this study[7]. It enables monitoring farm-agents economic results on an annual basis. Two main indicators are calculated: the crop gross margins and the farm income. Data for calculating gross margins and farm incomes are exported from the MAS model to FSEM (Figure 4). The module provides a set of indicators (Gini index, standard deviations of gross margins and annual incomes...) and graphs (e.g. farm income distribution within a group) to monitor farms economic results and individual and group level.

Figure 4: Hydrological model validation (with time on the x-axis, in 10-day intervals)



[6] The water reservoir does not exist in reality. It was a request from Mae La Ngun farmers during the participatory research project to test the effect of a water reservoir. They decided that the reservoir modeled will have a capacity of 8 000 m^3 (1000 m^2 surface by 8m depth) and will be used by Pha Nok Kok farmers to store water during the rainy season and irrigate during the dry season.

[7] FSEM is an open-source generic plug-in (http://sourceforge.net/projects/mas-farmeco) to any MAS model that includes a Farm and a Crop class.

Due to incomplete economic dataset some simplifications were made for this study. Variable costs for a given crop are the same for all farms, and fixed costs are not considered. Despite this lack of data, the following analysis remains relevant as the focus is more on assessing the changes in farm income distribution from one scenario to another.

3.2. Effect of weather condition on farm income for the baseline scenario (year 2005)

Table 4 presents the gross margins calculated by the FSEM module on the basis of the yield simulated by the model for baseline scenario. Simulated data were compared to the results of the Uplands Program's farm surveys of 2002 and 2003 (section 2 of the paper) and validated.

Table 4: Gross margins (in baht/rai) and average farm income (baht/year) - Baseline scenario

Farm group	Muang Kham downstream			Muang Kham upstream			Pha Nok Kok		
Weather condition	Rainy	Standard	Dry	Rainy	Standard	Dry	Rainy	Standard	Dry
sweet pepper	111 974	110 118	102 698	110 768	110 487	102 956	-	-	-
chrysanthemum	27 139	24 333	18 615	23 972	19 538	15 158	-	-	-
green bean	12 717	11 809	10 178	12 082	11 469	9427	-	-	-
gerbera	-	-	-	-	-	-	51 115	48 560	20430
cabbage	-	-	-	-	-	-	6302	6414	5950
lychee	-	-	-	-	-	-	1860	1479	1126
Chinese cabbage	5720	5049	4066	5408	4818	3543	8926	8989	7479
chayote	14 591	11 705	9535	14 498	11 518	9341	14 199	11 389	7962
Farm income	379 512	337 445	316 687	306 696	296 255	25 2480	175 704	167 403	79 839

Sweet pepper and gerbera have the highest gross margins in the area (sweet pepper for Muang Kham and gerbera for Pha Nok Kok). Lychee that used to be back in 1998/2000 a main source of income for Hmong farmers, such as in Pha Nok Kok, is not as important today due to the drop in price of this product. Sayote, as a consequent gross margin but due to a low market demand for this product, most farms have very few sayote trees[8]. Often farmers have three or four sayote trees around their house. Green bean also has a low demand. Sweet pepper in this area has a high demand due to a private company promoting sweet pepper contract farming that is based close to the village. This production has so much developed in the area (50% area increase between 2003 and 2005) that some farmers of Muang Kham turned to be traders for sweet pepper and are now buying products from their peers to sell it to the city or for export.

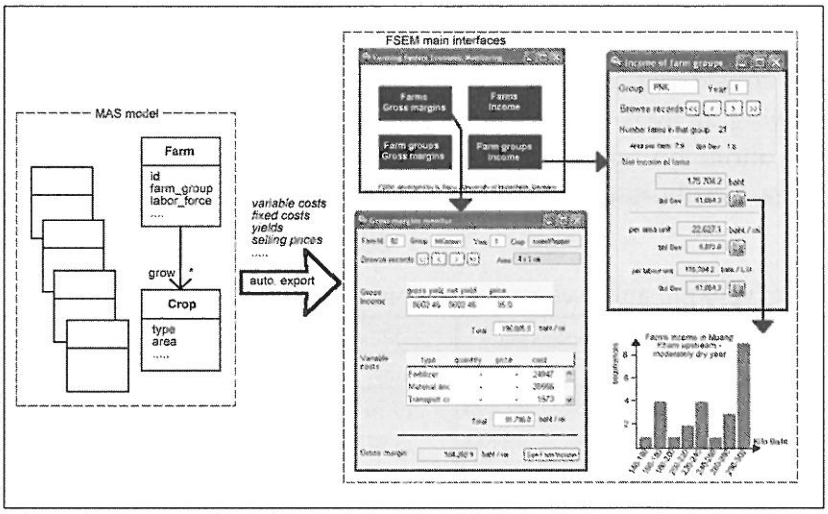
When it comes to farm incomes, great differences between farm groups are observed (Table 4). The absolute income is lower in Pha Nok Kok and is much more affected by drought than in Muang Kham (-50% instead of - 15% for Muang Kham). This is because gerbera, which is the main source of income, is very sensitive to droughts as compared to sweet pepper which uses drip irrigation. Hence, Muang Kham farmers have managed to secure and stabilize their income while Pha Nok Kok farmers depend on climatic conditions and have to adapt every year. However, Hmong farmers secure their incomes by other means such as pig production which has a cultural value, and can be traded for help.

Interestingly, simulation shows that stress events increase inequity in terms of income distribution within each farm group (Figure 6). In Muang Kham, farms whose income range from 280 000 to 300 000 Baht are the one producing sweet pepper. Other farms with lower incomes cultivate other crops. In all three groups, dry years tend to scatter farm incomes. This effect is more intense in the upstream part of Muang Kham than in its downstream part and is even more intense in Pha Nok Kok where the income standard deviation is increased by 15% in between a rainy and a dry year. These results confirm that inequity is directly related to sensitivity to water lack as Pha Nok Kok farms are much more dependent on rainfall than their downstream peers.

A detailed analysis showed that during a simulated dry year a number of farms manage to irrigate their gerbera and sustain their income (those obtain a gross margin for gerbera of 50 K.Baht/rai and an income of more than 200 KB); while the other farms fail to generate any income (- 1600 baht/ rai gross margin for gerbera and 30 KB income).

[8] Sayote is produced and consumed for its shoots.

Figure 5: FSEM module model-connection and interfaces



To confirm these observations, the Gini index of the different farm groups was calculated. The Gini coefficient is a measure of inequity developed by the Italian statistician C. Gini (1912). It is commonly used by institutions such as the World Bank to measure income inequality. The Gini coefficient is a number between 0 and 1, where 0 corresponds with perfect equality (where everyone has the same income) and 1 corresponds to a perfect inequality (where one person has all the income, and everyone else has zero income). The Gini index is the Gini coefficient expressed in percentage, and is equal to the Gini coefficient multiplied by 100. Table 5 shows that there is a significant increase of the Gini index in between a rainy and a dry year for all farm samples and especially in Pha Nok Kok (+23 points). This result demonstrates once again that income inequity among farms increases with drought intensity.

Table 5: Gini index of the different farm groups (baseline scenario)

	Rainy year	Standard year	Dry year
MK upstream	20	23	25
MK downstream	20	22	24
Pha Nok Kok	16	17	39
Whole area	*22*	*27*	*32*

3.3. Effect of alternative land uses and water reservoir on farm income

Similar calculations as above were made for the two alternative land uses (more sweet pepper or more gerbera) and for the scenario implementing a water reservoir in Pha Nok Kok. I here summarize the results obtained by focusing on income disparities among farms.

A radical increase of sweet pepper production in Muang Kham (SweetPepper scenario), has a significant positive effect on farms income in the concerned area (Table 6). Simulation indicates an increase of more than 100 000 baht during standard years. The gain is less important during rainy years as water saving brought by sweet pepper drip irrigation does not matter as much during rainy years. Interestingly, the income gain during dry years is not as important as during standard year. This is explained by the fact that simulated sweet pepper gross margins are lower in this scenario than in the baseline scenario. Hence, these results show that a shift from chrysanthemum to sweet pepper has a positive impact on farm income even though the production gross margin decreases. Additionally, the drop of sweet pepper gross margins is greater in the upstream part of Muang Kham than in the lower part as the upstream part is more affected by water scarcity than the downstream. These differences between the upstream and the downstream parts of Muang Kham result in a wider distribution of farms income in the upstream part than in the lower part as shown by the Gini index values in Table 6.

Table 6: Differences between the SweetPepper scenario and the baseline scenario for various economic indicators

	Area	Rainy	Standard	Dry
Variation of farm income	Muang Kham (MK)	+22%	+33%	+29%
	Pha Nok Kok	0%	0%	0%
Variation of sweet pepper gross margin	MK downstream	-1%	-2%	-4%
	MK upstream	-1%	-3%	-11%
Variation of Gini index	MK downstream	0	0	+3
	MK upstream	0	+2	+6
	Pha Nok Kok	0	0	0

When now considering a shift from vegetable production to gerbera in Pha Nok Kok village (Gerbera scenario), previous simulations had shown that it had a negative impact on water availability for both Pha Nok Kok farms and the ones located in the upstream part of Muang Kham. However, the economic results resulting from this scenario are more contrasted. If farm incomes in the upstream part of Muang Kham are clearly lower than in the baseline, this is not true for Pha Nok Kok farms which annual income increase significantly during rainy, standard and dry years. Yet the gross margins for gerbera are lower than in the baseline, due to a smaller water share obtained for each plot, but this agricultural shift would remain profitable for those farmers. However, this operation has a risk that during dry years the income from gerbera is not as profitable as for vegetables (-4% corresponding to 4 000 baht/year lost). Hence, in an insecure water supply context such as the one currently faced by Pha Nok Kok farmers, a mixed land use including vegetable production such as in the baseline scenario seems the most reasonable option. As for the previous scenario, simulation results show that this scenario would as well result in an increase of income inequity among farms of the same group (Table 7).

Table 7: Differences between the Gerbera scenario and the baseline scenario for various economic indicators

	Area	Rainy	Standard	Dry
Variation of farm income	MK downstream	0%	0%	0%
	MK upstream	-3.5%	-11%	-4.5%
	Pha Nok Kok	0+28%	+28%	-4%
Variation of gerbera gross margin	Pha Nok Kok	-5%	-6%	-11%
Variation of Gini index	Muang Kham	0	+2	+6
	Pha Nok Kok	+2	+2	+3

A water reservoir in Pha Nok Kok village allows reducing the shortage period during standard and dry years (it has no effect during rainy years) by almost two-third in Pha Nok Kok and by 15% in the upstream part of Muang Kham. This gain in water supply has almost no consequence on economic results in Muang Kham; however, it has a significant positive impact for Pha Nok Kok farm incomes due to an increase of gerbera, as well as lychee, gross margins (Table 8). Lychee production benefits relatively more than gerbera, yet the absolute increase in Baht is higher for gerbera (+1 740 baht/rai as compared to +330 baht/rai for lychee during dry years). Interestingly this gain of income benefits to all farms in Pha Nok Kok and even tends to reduce income inequity in this village during dry years (Table 8).

Table 8: Differences between the baseline with water reservoir scenario for various economic indicators

	Area	Rainy	Standard	Dry
Variation of farm income	Muang Kham	0%	0%	0%
	Pha Nok Kok	0%	+2%	+10%
Variation of gross margin in Pha Nok Kok (PNK)	Gerbera in PNK	0%	+1%	+8.5%
	Lychee in PNK	-0%	+7%	+29%
Variation of Gini index	Muang Kham	0	0	+1
	Pha Nok Kok	0	0	-3

4. DISCUSSION

Two main aspects are discussed in this section. First we draw some conclusions on how weather conditions, changes in land use and innovations affect farm income disparity and we outline the role of adaptation in those processes. Second, we discuss the benefit of using multi-agent systems to monitor heterogeneity and inequity among farms and claim for a wider use of these techniques in agricultural studies.

4.1. Inequity and response to changes

Simulation results show that stress events such as dry years (a year with less rainfall than usual; 1 000 mm instead of 1 400 mm per year in average) or changes such as introduction of innovation or land use changes, tend to increase inequity among individuals. In this paper, inequity is measured through the Gini index.

While a number of farms during a dry year achieve to maintain an income equivalent to a standard year, the income of other farms is reduced significantly in a range of 10 to 30%. This differentiation of responses to a same cause is due to a heterogeneity of access to water and to crop choices that can be more or less sensitive to water stress. This differentiation is even greater when looking at land use change. Indeed, the global average farm income increases but a detailed analysis of the results shows that some farms suffer an income drop while others enrich. Hence, increasing gerbera production in Pha Nok Kok, or sweet pepper in Muang Kham, results in increasing farm income disparity within the agricultural area where those production shifts occur.

Considering a same amount of water supply, a cropping intensification in the upstream of the catchment results in income depletion and increasing income disparities in the downstream. This was already foreseen through the simulated water shortage presented in the second section of this paper. Now, with an increase of water supply such as in the scenario implementing a water reservoir, income disparities are reduced. In brief, these results show that the response to an increasing water demand or a diminishing water supply is increasing inequity among producers.

Similar results can be found in the literature. Taking the example of the green revolution, Gretchen and Ehrlich (1996) argue that "technological progress in farming can also work against equity, hurting farmers who are less able to adopt innovations rapidly (often the smaller family farms), while favoring nonfarm consumers". Hyytinen and Toivanen's econometric model (2005) shows that "when combined with income inequality, technical progress that manifests itself as an enlargement of consumers' choice set leads to increased welfare inequality, and not only to improved welfare to all". Much has to be learned as well from the vulnerability perspective which interest is - among others - in socio-economical impacts of environmental hazards. Hazards are defined as perturbation or stress/stressor in the system and vulnerability as is the degree to which a system is likely to experience harm due to a hazard exposure (Turner *et al.*, 2003a). In an application of drought impact on Mexican farms (including yield response), the authors show that responses to hazards depend in part on individual access to biophysical and social resources and that "distinctions in access lead to significant differences in individual household vulnerability and response option" (Turner *et al.*, 2003b). For instance, Koné *et al.* (2006) advocate that the resilience of individuals – which characterizes their capacity to adapt to changes – depends on factors that are not uniformly distributed and not always quantifiable, such as local knowledge, social network or financial capital.

In contexts of limited resources, stress events such as sudden changes tend to deepen inequity among user groups due to heterogeneity of resource access and means. In such situations, and considering that conserving access rights is more and more difficult because of increasing interdependencies and pressure on resources, the only sustainable response of producers is to adapt their production system. To this aim, the model presented in this paper is incomplete as it does not implement changes of production strategy which in reality would necessarily occur as soon as a farm suffers from a sudden change of the environment. The recommendations of the World development report 2008 (World Bank, 2008) on differentiated development policies should thus be applied together with mitigation initiatives to facilitate adaptation or even reconversion of the weakest agricultural producers.

It is a necessity to now consider that changes such as climate change, as well as innovation, induce perturbations in the production systems that necessarily induce some to lose. In such contexts, win/win situation does not prevail.

4.2. The use of MAS for agricultural studies on inequity

We are prompted by today's situation to concentrate our research efforts on inequity, their causes and relation to climate change. One can consider two main key factors contributing to the dynamics of inequity: the interaction system (which for example in this paper is the hydrographic network) and the heterogeneity of resource access and users' needs (here, the farms). Among other tools, multi-agent systems are especially well equipped to manage such factors and this is why I encourage its use in the context of inequity assessment.

Climate change, increasing commercial exchanges, reinforcement of competition between firms, all these processes increase the probability to have strong perturbations, sudden changes or break points in the environment of agroeconomic systems. Flexibility and adaptation are the new means of firms whatever their size. Farmers in transforming countries directly face those types of perturbations. To better understand inequities it is necessary to better understand how changes and perturbations affect disparities. The multi-agent simulation tool here presented offers great possibilities in terms of analysis which need to be further developed. In this paper, I focused on income heterogeneity and analyzed how it varies with weather condition, variation in water supply and in water demand, within a farm population which access to water is heterogeneous and interdependent. In parallel, other type of studies are undertook to better understand those processes, such as analyzing individual trajectories, evaluating adaptive strategies such as in Zhai *et al.* (2009) or Lacombe *et al.* (2005), studying the impact of interaction structure and networks on disparities through simulations such as for instance in Dung *et al.* (2005) or looking at synergies between adaptation, innovation and mitigation as proposed by the Asian Development Bank (2009).

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